Telecommunications
Radar

Phase-Coded Pulse Compression

Courseware Sample
52919-F0
The purchaser shall receive a single right of use which is non-exclusive, non-time-limited and limited geographically to use at the purchaser's site/location as follows.

The purchaser shall be entitled to use the work to train his/her staff at the purchaser's site/location and shall also be entitled to use parts of the copyright material as the basis for the production of his/her own training documentation for the training of his/her staff at the purchaser's site/location with acknowledgement of source and to make copies for this purpose. In the case of schools/technical colleges, training centers, and universities, the right of use shall also include use by school and college students and trainees at the purchaser's site/location for teaching purposes.

The right of use shall in all cases exclude the right to publish the copyright material or to make this available for use on intranet, Internet and LMS platforms and databases such as Moodle, which allow access by a wide variety of users, including those outside of the purchaser's site/location.

Entitlement to other rights relating to reproductions, copies, adaptations, translations, microfilming and transfer to and storage and processing in electronic systems, no matter whether in whole or in part, shall require the prior consent of Festo Didactic.

Information in this document is subject to change without notice and does not represent a commitment on the part of Festo Didactic. The Festo materials described in this document are furnished under a license agreement or a nondisclosure agreement.

Festo Didactic recognizes product names as trademarks or registered trademarks of their respective holders.

All other trademarks are the property of their respective owners. Other trademarks and trade names may be used in this document to refer to either the entity claiming the marks and names or their products. Festo Didactic disclaims any proprietary interest in trademarks and trade names other than its own.
## Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="danger.png" alt="DANGER" /></td>
<td><strong>DANGER</strong> indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.</td>
</tr>
<tr>
<td><img src="warning.png" alt="WARNING" /></td>
<td><strong>WARNING</strong> indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.</td>
</tr>
<tr>
<td><img src="caution.png" alt="CAUTION" /></td>
<td><strong>CAUTION</strong> indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.</td>
</tr>
<tr>
<td><img src="caution.png" alt="CAUTION" /></td>
<td><strong>CAUTION</strong> used without the <em>Caution, risk of danger</em> sign, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.</td>
</tr>
<tr>
<td><img src="electric.png" alt="Caution, risk of electric shock" /></td>
<td>Caution, risk of electric shock</td>
</tr>
<tr>
<td><img src="hot.png" alt="Caution, hot surface" /></td>
<td>Caution, hot surface</td>
</tr>
<tr>
<td><img src="danger.png" alt="Caution, risk of danger" /></td>
<td>Caution, risk of danger. Consult the relevant user documentation.</td>
</tr>
<tr>
<td><img src="lifting.png" alt="Caution, lifting hazard" /></td>
<td>Caution, lifting hazard</td>
</tr>
<tr>
<td><img src="belt.png" alt="Caution, belt drive entanglement hazard" /></td>
<td>Caution, belt drive entanglement hazard</td>
</tr>
<tr>
<td><img src="chain.png" alt="Caution, chain drive entanglement hazard" /></td>
<td>Caution, chain drive entanglement hazard</td>
</tr>
<tr>
<td><img src="gear.png" alt="Caution, gear entanglement hazard" /></td>
<td>Caution, gear entanglement hazard</td>
</tr>
<tr>
<td><img src="hand.png" alt="Caution, hand crushing hazard" /></td>
<td>Caution, hand crushing hazard</td>
</tr>
<tr>
<td><img src="radiation.png" alt="Notice, non-ionizing radiation" /></td>
<td>Notice, non-ionizing radiation</td>
</tr>
<tr>
<td><img src="documentation.png" alt="Consult the relevant user documentation" /></td>
<td>Consult the relevant user documentation.</td>
</tr>
<tr>
<td><img src="direct.png" alt="Direct current" /></td>
<td>Direct current</td>
</tr>
</tbody>
</table>
## Safety and Common Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>〜</td>
<td>Alternating current</td>
</tr>
<tr>
<td>〜〜</td>
<td>Both direct and alternating current</td>
</tr>
<tr>
<td>〜〜〜</td>
<td>Three-phase alternating current</td>
</tr>
<tr>
<td>⚡</td>
<td>Earth (ground) terminal</td>
</tr>
<tr>
<td>⚡</td>
<td>Protective conductor terminal</td>
</tr>
<tr>
<td>⚡</td>
<td>Frame or chassis terminal</td>
</tr>
<tr>
<td>⚡</td>
<td>Equipotentiality</td>
</tr>
<tr>
<td>⚡</td>
<td>On (supply)</td>
</tr>
<tr>
<td>⚡</td>
<td>Off (supply)</td>
</tr>
<tr>
<td>⚡</td>
<td>Equipment protected throughout by double insulation or reinforced insulation</td>
</tr>
<tr>
<td>⚡</td>
<td>In position of a bi-stable push control</td>
</tr>
<tr>
<td>⚡</td>
<td>Out position of a bi-stable push control</td>
</tr>
</tbody>
</table>
# Table of Contents

**Preface** ................................................................................................................................................ XI

**About This Manual** ........................................................................................................................... XIII

**To the Instructor** ................................................................................................................................ XV

**Unit 1  Pulse Compression Systems** .................................................................................................. 1

<table>
<thead>
<tr>
<th>DISCUSSION OF FUNDAMENTALS</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse systems and pulse compression</td>
<td>1</td>
</tr>
<tr>
<td>An inherent problem</td>
<td>2</td>
</tr>
<tr>
<td>Pulse compression</td>
<td>3</td>
</tr>
</tbody>
</table>

**Ex. 1-1  Introduction to Phase-Coded Pulse Compression** ................................................. 5

<table>
<thead>
<tr>
<th>DISCUSSION</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar signals</td>
<td>5</td>
</tr>
<tr>
<td>Average and peak power of radar signals</td>
<td>7</td>
</tr>
<tr>
<td>Radar signal bandwidth</td>
<td>7</td>
</tr>
<tr>
<td>Difficult tradeoffs</td>
<td>8</td>
</tr>
<tr>
<td>Radar sensitivity</td>
<td>8</td>
</tr>
<tr>
<td>Average transmitted power</td>
<td>9</td>
</tr>
<tr>
<td>Receiver sensitivity</td>
<td>9</td>
</tr>
<tr>
<td>Pulse width</td>
<td>10</td>
</tr>
<tr>
<td>A review of range resolution</td>
<td>10</td>
</tr>
<tr>
<td>Pulse compression to the rescue</td>
<td>13</td>
</tr>
<tr>
<td>Pulse compression coding</td>
<td>14</td>
</tr>
<tr>
<td>Demodulation</td>
<td>15</td>
</tr>
<tr>
<td>Matched filtering</td>
<td>17</td>
</tr>
<tr>
<td>Phase-coded pulse compression processing</td>
<td>19</td>
</tr>
<tr>
<td>Disadvantages of phase-coded pulse compression</td>
<td>20</td>
</tr>
<tr>
<td>Range sidelobes</td>
<td>21</td>
</tr>
<tr>
<td>Summary of advantages and disadvantages</td>
<td>21</td>
</tr>
<tr>
<td>Observations on the PPI display</td>
<td>22</td>
</tr>
<tr>
<td>The Phase-Coded Pulse Compression Processor</td>
<td>24</td>
</tr>
<tr>
<td>The Dual-Channel Sampler</td>
<td>26</td>
</tr>
<tr>
<td>Normalization</td>
<td>27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROCEDURE</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup</td>
<td>27</td>
</tr>
<tr>
<td>A review of the LVRTS software</td>
<td>28</td>
</tr>
<tr>
<td>Operation without pulse compression</td>
<td>30</td>
</tr>
<tr>
<td>Range resolution without pulse compression</td>
<td>34</td>
</tr>
<tr>
<td>Phase-coded pulse compression</td>
<td>38</td>
</tr>
<tr>
<td>Recalibration</td>
<td>39</td>
</tr>
<tr>
<td>Observation of phase codes</td>
<td>39</td>
</tr>
<tr>
<td>Range resolution with compression</td>
<td>43</td>
</tr>
<tr>
<td>Observations using the Oscilloscope</td>
<td>43</td>
</tr>
<tr>
<td>Observations on the PPI</td>
<td>48</td>
</tr>
</tbody>
</table>
# Table of Contents

### Ex. 1-2 Basic Concepts and Techniques ......................................................... 55

- Discussion .................................................................................. 55
- Phase-code modulation ........................................................... 55
- Generation of phase codes ....................................................... 57
  - The Phase-Coded Pulse Compression Processor ................. 57
- Bandwidth of phase-coded signals .......................................... 58
- Compression of phase-coded signals ....................................... 59
  - Correlation ........................................................................... 59
  - Cross-correlation ............................................................... 60
  - Autocorrelation ................................................................. 62
  - Lag ..................................................................................... 63
  - Autocorrelation of a rectangular radar pulse .................... 64
  - Autocorrelation of a coded radar pulse ............................. 68
  - Pulse compression in a quadrature receiver ...................... 72
- Optimal binary sequences ......................................................... 72
- Important parameters in pulse compression ......................... 74
  - Definitions ........................................................................ 74
  - Examples ........................................................................... 76
- All known Barker codes and their properties ......................... 77

### PROCEDURE ..................................................................................... 78
- Setup and connections ............................................................. 78
- Autocorrelation of a rectangular pulse .................................... 80
- Autocorrelation of a Barker-encoded pulse ............................ 82
- Barker codes and their properties ......................................... 83
- Pulse compression in a quadrature receiver .......................... 86

### Ex. 1-3 Pulse Compression Ratio and SNR Improvement .......................... 89

- Discussion ................................................................................. 89
- Detection of targets ................................................................. 89
- The radar range equation .......................................................... 91
  - The classic form ................................................................ 91
  - Including losses in the equation ......................................... 94
- Noise ...................................................................................... 95
  - Thermal noise .................................................................. 95
  - Noise added by the receiver .............................................. 97
- Radar range equation for a pulse radar with a matched input filter .................................................... 99
- Taking probabilities into account ......................................... 100
- Phase-coded pulse compression ............................................. 101
- What to conclude ................................................................ 101
Table of Contents

PROCEDURE .................................................................................. 104
   Setup and connections.......................................................... 104
   Determining the maximum range without pulse
       compression................................................................................. 106
       Adjust the offsets and measure the system noise .................. 107
       Calculate the desired signal level ........................................... 108
       Adjust the offsets and position the target to obtain the
           desired level ............................................................................ 109
       Measure the maximum target range without pulse
           compression ............................................................................. 111
       Observe the signal without pulse compression on the PPI
           display ..................................................................................... 111
   Determining the maximum range with pulse compression ... 113
       Adjust the offsets and measure the system noise .................. 113
       Calculate the desired signal level ........................................... 113
       Position the target to obtain the desired level...................... 114
       Measure the maximum target range with pulse compression .. 114
   Measured and theoretical range improvements .................... 114
       Observe the signal with pulse compression on the PPI
           display ..................................................................................... 114
   The effect of matched filtering on the signal-to-noise ratio... 115

Ex. 1-4 Phase-Code Compression Processing .......................... 123

DISCUSSION .................................................................................. 123
   A deeper look into matched filters ......................................... 123
   Signals and systems ............................................................. 123
   Time and frequency domains ................................................ 124
       The time domain ................................................................. 124
       Time-domain notation ......................................................... 125
       The frequency domain ......................................................... 125
       Frequency-domain notation ................................................ 127
   Linear time-invariant (LTI) systems.................................... 127
   Signal superposition and decomposition with LTI systems .. 127
       Decomposition in the frequency domain ......................... 128
       Decomposition in the time domain ....................................... 130
   Frequency- and time-domain characteristics of systems...... 131
       Frequency response ............................................................. 131
       Filtering as multiplication in the frequency domain .......... 132
       Impulse response ................................................................. 133
       Formal definitions for discrete LTI systems ....................... 135
   Convolution ........................................................................... 135
       Filtering as convolution ..................................................... 137
       Impulse response of a matched filter ................................. 138
       Convolution with the impulse response ......................... 139
   What to conclude ................................................................. 141
Table of Contents

PROCEDURE ................................................................................. 142
  Set up ....................................................................................... 142
    Connections and adjustments .................................................. 143
  Observe coded pulse before and after compression .......... 144
  Observe code sequences and impulse responses of the
correlator .................................................................................. 146
    Code sequences ..................................................................... 146
    Impulse responses .................................................................. 148
  Impulse decomposition and synthesis ................................. 151

Unit 2 Reducing Range Sidelobes .............................................. 159

DISCUSSION OF FUNDAMENTALS ............................................. 159
  The range sidelobe problem ..................................................... 159
  Approaches to limiting or reducing range sidelobes ........... 159

Ex. 2-1 Near-Perfect, Pseudo Random, Combined Barker, and
Polyphase Codes ......................................................................... 161

DISCUSSION ............................................................................... 161
  Biphase codes ........................................................................ 161
  Barker codes .......................................................................... 161
  The quest for better codes .................................................... 162
  Near-perfect codes ............................................................... 162
  Pseudorandom codes ............................................................ 165
  Combined Barker codes ......................................................... 168
  Polyphase codes .................................................................... 170

PROCEDURE ................................................................................. 174
  Setup and connections ............................................................ 174
  Comparing PSL and ISL for different codes ....................... 176
    Barker 13 ............................................................................. 176
    PRBS 15 .............................................................................. 179
    NP 15 ................................................................................ 186
    PRBS 31 and NP 31 .............................................................. 188
    Barker 5 x 7 ......................................................................... 190

Ex. 2-2 Golay Codes and Optimum Mismatched Filters .......... 195

DISCUSSION ............................................................................... 195
  The need for sidelobe suppression ........................................ 195
  Approaches to sidelobe suppression ..................................... 195
  Golay sidelobe-cancelling codes ......................................... 196
  Optimum mismatched filtering ............................................. 197
    Loss in processing gain ....................................................... 198
# Table of Contents

**PROCEDURE** .................................................................................. 200  
Setup and connections .......................................................... 200  
Golay codes .......................................................................... 201  
Mismatched filtering with Barker codes ......................... 204  
Mismatched filtering with combined Barker codes .......... 204  
Loss in processing gain (LPG) .............................................. 204  
Mismatched filter coefficients ................................................ 207  

**Appendix A**  
Equipment Utilization Chart ..................................................... 219  

**Appendix B**  
Glossary of New Terms ............................................................. 221  

**Appendix C**  
Setting up the Radar Training System with Pulse Compression .............................................................................. 227  
Introduction ........................................................................... 227  
The main elements of the Radar Training System .......... 227  
Mounting the Radar Antenna on the Rotating-Antenna Pedestal ................................................................................ 228  
Positioning the various elements of the Radar Training System ................................................................................ 228  
Setting the height of the target table................................. 230  
Placing the modules.............................................................. 231  

**Appendix D**  
Calibration of the Radar Training System............................ 233  
Introduction ........................................................................... 233  
I. Connections and initial adjustments ............................... 233  
II. DC Offset checking and adjustment ............................... 235  
III. Gain checking and adjustment ........................................ 236  
IV. Origin calibration.............................................................. 240  

**Appendix E**  
Using the Phase-Coded Pulse Compression Processor ...... 243  
The Phase-Coded Pulse Compression Processor ............... 243  
The Dual-Channel Sampler ..................................................... 245  
Effective time base when observing time stretched signals 246  
Normalization........................................................................... 246  

Index of New Terms ........................................................................................... 247  
Acronyms ........................................................................................................... 249  
Bibliography ....................................................................................................... 251
Preface

Radar systems in the 1940's and 1950's used magnetrons as a source of microwave power. The magnetron was capable of generating short, high power pulses of RF energy. However, this reliable and low-cost device had some serious drawbacks. Among others, small changes in the frequency of the generated radar signal made it difficult to perform moving target indication (MTI) processing in order to reduce ground and rain clutter in civil air-traffic management systems. For military users, this made it difficult to use MIT processing in order to see detect aircraft deliberately obscured by chaff.

Precise frequency stability was achieved by replacing the magnetrons with “driven amplifier” transmitters, such as the Klystron and the travelling-wave tube (TWT). These devices were used to amplify a very stable, low power frequency source and this resulted in much improved clutter rejection. Unfortunately, in order to obtain an average transmitted power high enough to provide the desired maximum range, the pulses had to quite long, typically a hundred times longer than an equivalent magnetron pulse.

This led to a serious problem because the longer pulse made it impossible to resolve closely spaced targets, a capacity especially important for military applications. During World War II, for example, attacking aircraft took advantage of the poor resolution of radar systems by flying in close formation, which caused the radar operator to see only one target rather than several.

Pulse compression provided an elegant solution to this problem. The development of pulse compression was the joint invention of many people with various skills and specialties in diverse institutions in several countries. It required a great deal of imagination and perseverance as well as mathematical expertise with Fourier transforms and convolution theory.

Early pulse compression systems used passive equipment such as surface acoustic wave (SAW) devices to generate and compress frequency-modulated waveforms. Later, innovations in digital processing made it possible to generate and compress phase-coded waveforms digitally. These innovations include the development of high-speed analog-to-digital converters, integrated circuits, memory devices, powerful microprocessors, and field programmable gate arrays (FPGAs), as well as improved software engineering methods.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.
About This Manual

*Radar* is the courseware series which accompanies the Radar Training System. This manual provides instruction in phase-coded pulse compression. It is divided into two units:

Unit 1, *Pulse Compression Systems*, provides a solid understanding of the fundamentals of pulse compression and the principles and technology used in phase-coded pulse compression.

Unit 2, *Reducing Range Sidelobes*, discusses the main drawback of pulse compression and the techniques used to minimize this problem.

The exercises in this manual provide a systematic and realistic means of learning the subject matter. Each exercise contains:

- a clearly defined *Exercise Objective*.
- a *Discussion* of the theory involved.
- a *Procedure Summary* which provides a bridge between the theoretical Discussion and the laboratory Procedure.
- a detailed, step-by-step laboratory Procedure in which the student observes and measures important phenomena. Illustrations facilitate connecting the modules and guide the student's observations. Throughout the Procedure, questions direct the student's thinking process and help in understanding the principles involved.
- a *Conclusion* to summarize the material presented in the exercise.
- a set of *Review Questions* to verify that the material has been well assimilated.

**Safety with RF fields**

When studying radar systems, it is very important to develop good safety habits. Although microwaves are invisible, they can be dangerous at high levels or for long exposure times. The most important safety rule when working with microwave equipment is to avoid exposure to dangerous radiation levels.

In normal operation, the radiation levels in the Lab-Volt Radar Training System are too low to be dangerous. The power radiated by the Radar Transmitter in CW mode is typically 2 mW from 8 GHz to 10 GHz. The maximum power density produced by the Lab-Volt Radar Training System is thus equal to 0.08 mW/cm² from 8 GHz to 10 GHz.

In order to develop *good safety habits*, you should, whenever possible, set the RF Power switch to the STANDBY position before placing yourself in front of the transmitting antenna. Your instructor may have additional safety directives for this system.
For your safety, do not look directly into the source of microwave radiation while power is being supplied to the Radar Transmitter.
To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.
Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide
Introduction to Phase-Coded Pulse Compression

**EXERCISE OBJECTIVE**

When you have completed this exercise, you will be familiar with the concept of phase-coded pulse compression and the advantages of using this technique in a pulse radar system.

**DISCUSSION OUTLINE**

The Discussion of this exercise covers the following points:

- Radar signals
  - Average and peak power of radar signals. Radar signal bandwidth.
- Difficult tradeoffs
- Radar sensitivity
  - Average transmitted power. Receiver sensitivity. Pulse width.
- A review of range resolution
- Pulse compression to the rescue
- Pulse compression coding
- Demodulation
- Matched filtering
- Phase-coded pulse compression processing
- Disadvantages of phase-coded pulse compression
  - Range sidelobes.
- Summary of advantages and disadvantages
- Observations on the PPI display
- The Phase-Coded Pulse Compression Processor
  - *The Dual-Channel Sampler. Normalization.*

**DISCUSSION**

**Radar signals**

As you know, the term **RADAR** is an acronym for RAdio Detection And Ranging. However, although all radars must be able to detect the presence of objects (targets), not all radars can determine their range.

Consider a continuous-wave (CW) radar, as shown in Figure 1-2.

![Figure 1-2. Continuous-wave (CW) radar.](image)

A CW radar transmits an unmodulated sinusoidal RF signal. Although this type of radar can detect the presence of a target and, using the Doppler shift, determine
its radial velocity, it cannot determine the range of the target. The reason for this is because there is never any change or “marker” in the signal that allows the radar to measure the round-trip transit time of the signal.

In order to allow the radar to determine the range of targets, some periodic change must occur in the transmitted signal. The simplest and most common technique is to transmit pulses of RF energy, rather than a continuous wave, as shown in Figure 1-3.

![Figure 1-3. Pulsed radar.](image)

With pulsed radar, short RF pulses are produced by the transmitter and are radiated by the antenna. Targets reflect echo pulses back to the antenna and these echo pulses are demodulated and detected by the receiver. The range of a target is determined by the time it takes for a pulse to make the round trip.

\[
R = \frac{cT_R}{2}
\]

(1-1)

where

- \( R \) is the target range
- \( c \) is the speed of light \((3 \times 10^8 \text{ m/s})\)
- \( T_R \) is the round-trip transit time

Figure 1-4 shows a commonly used method of generating the pulsed RF signals in the transmitter. A CW RF signal is generated and is subsequently amplitude modulated by a baseband pulse signal. The result consists of pulses of RF energy. Each pulse may contain thousands of cycles of the sinusoidal waveform.

Note that the RF pulses are, in a sense, “cut out” of a continuous sinusoidal signal. As a result, the phase relationship of the pulse signal with respect to the CW signal is stable. This type of pulsed RF signal is said to be **coherent**.
As already seen in other manuals of the *Radar* series, the rate at which the pulses are produced is called the **pulse repetition frequency (PRF)**. The **interpulse period**, or **pulse repetition time**, is the time from the beginning of one pulse to the beginning of the next. The **pulse width** is the duration of each pulse.

**Average and peak power of radar signals**

Most radar transmitters operate in saturation. This means that the power is either fully on or off. During a pulse, the amplitude of the signal is kept at its maximum value; there is no variation in amplitude.

Suppose the CW and pulsed RF signals in Figure 1-4 have the same amplitude, and that the power of the CW signal is $P$. Then the power of the pulsed RF signal *during a pulse* is also $P$. This is referred to as the **peak power** or the **pulse power** of the pulsed waveform.

The **average power** of the pulsed waveform depends on the duty cycle and is less than the peak power:

$$P_{\text{avg}} = P \times \text{Duty cycle}$$
$$= P \times \frac{\text{Pulse width}}{\text{Interpulse period}}$$
$$= P \times T \times \text{PRF}$$

**Radar signal bandwidth**

In theory, an unmodulated CW signal that has no beginning and no end contains only one frequency. Its bandwidth is therefore zero. A pulsed RF signal, on the other hand, contains many frequency components. In theory, the bandwidth of a pulsed signal is infinite. However, the power of frequency components that are far from the carrier frequency is negligible.
There are different ways to express the bandwidth of a pulsed signal. A common one is the reciprocal of the pulse width. This is called the Rayleigh bandwidth.

\[ B \approxeq \frac{1}{\tau} \]  

(1-2)

where \( B \) is the Rayleigh bandwidth of the pulsed RF signal

\( \tau \) is the pulse width

**Difficult tradeoffs**

Besides detecting targets, a pulsed radar must be able to discriminate between targets that are close together in range. The ability of a radar system to resolve targets along the same line of sight is called the range resolution.

To summarize, high sensitivity and fine range resolution are both required to ensure that the radar system can:

- reliably detect targets within the desired range, and
- discriminate between targets that are close together in range.

**Radar sensitivity**

The term radar sensitivity is often used to refer to the capacity of the radar system to detect targets in the presence of interfering phenomena such as noise and clutter. Anything that can increase this capacity is said to increase the radar’s sensitivity.

Since the power returned from targets decreases rapidly with range, radar sensitivity is directly related to the maximum operating range of the radar system. When all other factors are equal (such as the radar cross section of the targets), the greater the radar sensitivity, the greater the maximum range of the radar system.

Many different factors affect radar sensitivity. Some of these factors, such as the presence of clutter, are beyond the control of the system designers and operators. Other factors are mainly determined by the design of the radar system and its operating parameters. These factors can be modified to improve the radar’s performance. Two such factors affecting radar sensitivity are:

- the average power transmitted in the direction of the target, and
- the receiver sensitivity.
Average transmitted power

As the radar antenna scans the space around it, it radiates RF power in different directions. An increase in the average power transmitted in the direction of a target increases the average power reflected by the target, and therefore increases the signal-to-noise ratio at the input of the receiver.

This in turn increases the signal-to-noise ratio of the video signal at the output of the receiver (before the detection stage). The greater the signal-to-noise ratio in the video signal, the greater the ability of the radar system to detect the target.

Table 1-1 shows a number of methods that can increase the average power transmitted in the direction of the target. Unfortunately, each of these methods presents one or more serious drawbacks.

Table 1-1. Methods to increase the average power transmitted in the direction of the target.

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase the peak pulse power of the transmitter</td>
<td>Increases the energy per pulse, which increases the maximum operating range and makes targets more visible in noise.</td>
<td>• A 16-fold increase in peak power is needed to double the range. • Increases equipment cost and weight. • May cause cooling problems, arcing, and breakdown, reducing reliability. • Increases safety hazards. • Solid state transmitters and phased-array antennas cannot operate at high peak power.</td>
</tr>
<tr>
<td>Increase the PRF</td>
<td>Increases the number of pulses returned from the target per unit time.</td>
<td>• Reduces the maximum unambiguous range (the maximum range before second trace echoes begin to occur).</td>
</tr>
<tr>
<td>Increase the antenna dwell time (e.g. reduce the antenna rotation speed)</td>
<td>Increases the number of pulses returned from the target per unit time.</td>
<td>• Decreases the radar display update rate. • Increasing the antenna dwell time may be impossible if high time resolution is required for rapidly changing targets.</td>
</tr>
<tr>
<td>Increase the antenna gain</td>
<td>Concentrates the transmitted power into a narrower beam, increasing the energy per pulse in the direction of the target.</td>
<td>• Increases the size, weight, cost, structural complexity, and dimensional tolerance requirements of the antenna system.</td>
</tr>
<tr>
<td>Increase the pulse width</td>
<td>Increases the energy per pulse.</td>
<td>• Deteriorates the range resolution of the radar.</td>
</tr>
</tbody>
</table>

Receiver sensitivity

A radar receiver demodulates the received signal, which consists of reflected pulses of RF energy and noise, shifting the signal down to the baseband. It then detects and processes the baseband video signal. Detection involves comparing the video signal to a threshold. If the signal exceeds the threshold, a detection occurs, which can either be a real target or a false alarm.
After the detection stage, the signal must be processed. Analog moving target indication (MTI) and digital moving target detection (MTD) are two types of processing commonly used with pulse radar systems.

Detection and processing can only be accomplished if the video signal meets or exceeds a specific signal-to-noise ratio (S/N or SNR). This requirement is met if the signal strength at the input of the receiver meets or exceeds a certain minimum input signal power level. This minimum input signal power \( S_{\text{min}} \) is called the **receiver sensitivity**. This value depends on the \( S/N \) at the receiver input, the amount of noise added by the receiver, the receiver bandwidth, and various other factors.

All receivers add thermal noise to the already noisy RF input signal. Since the first stage of the receiver makes the greatest noise contribution, the receiver uses a low-noise amplifier (LNA) at the input. The receiver sensitivity can be increased by using a higher quality, and more costly, LNA. There is a limit to the improvement that can be obtained, however, since the received signal is already contaminated by noise.

**Pulse width**

By far, the easiest way to increase the radar sensitivity is to increase the pulse width of the transmitted signal. This increases the energy per transmitted pulse and hence the average power reflected by the target and present at the input of the receiver. As already mentioned, however, increasing the pulse width deteriorates the range resolution and can prevent the radar system from distinguishing multiple targets that are close together in range.

**A review of range resolution**

The **range resolution** of a radar system is defined as the minimum separation in range of two targets of equal cross section that can be resolved as separate targets. In theory, two targets along the same line of sight from the radar antenna can be resolved (will produce two distinguishable blips on the radar display) if they are separated by a distance equal to or greater than the range resolution. If the separation is less than the range resolution, the two targets will not be resolved and will appear as a single target.

The range resolution of a radar is mostly determined by the pulse width (duration) of the radar pulses. The pulse width determines the distance between the leading and trailing edges of the pulse as it travels through space. This distance is called the **pulse length**.

The pulse length is equal to the pulse width times the speed of light:

\[
L_p = \tau c
\]

where

- \( L_p \) is the pulse length (in meters)
- \( \tau \) is the pulse width (in seconds)
- \( c \) is the speed of light (3 x 10^8 m/s)
Figure 1-5 and Figure 1-6 illustrate the effect of pulse length on range resolution.

In Figure 1-5a, the pulse length of the transmitted pulse, represented by the length of the arrow, is less than twice the target separation. In Figure 1-5b, the leading edge of the transmitted pulse strikes the near target. In Figure 1-5c, the leading edge of the transmitted pulse strikes the far target. By this time, the echo from the near target has begun to travel towards the radar. In Figure 1-5d, the far target is still reflecting the transmitted pulse, whereas the echo has left the near target. In Figure 1-5e, both echoes have left their targets, and there is a considerable separation between the echo pulses. The radar will be able to resolve the two targets, which will appear as two distinct blips on the display.
Figure 1-6 shows the effect of increasing the pulse length. In this figure, the length of the transmitted pulse is equal to twice the target separation. When the two echoes have left their targets, there is no separation between them, as shown in Figure 1-6e. In this case, the radar will not likely be able to resolve the two targets. They will be displayed as one long blip, rather than two distinct blips.

Theoretically, a radar should be able to resolve two targets as long as their range separation is not less than one half the pulse length, and the two echo signals are equally strong. In practice, however, because of the performance limitations of various circuits, and because of the presence of noise, it may be necessary for the separation to be substantially greater than one half the pulse length in order for the targets to be resolved.

Since the Rayleigh bandwidth of a baseband pulse signal is equal to the reciprocal of the pulse width, the theoretical range resolution can be expressed either in terms of pulse length, pulse width, or bandwidth:

\[
\Delta R = \frac{L_p}{2} = \frac{\tau c}{2} \cong \frac{c}{2B}
\]  

(1-4)

where \( \Delta R \) is the range resolution
\( L_p \) is the pulse length
\( \tau \) is the pulse width
\( c \) is the speed of light
\( B \) is the Rayleigh bandwidth of the pulse signal

Note that the smaller the value of \( \Delta R \), the better the range resolution of the radar.
As already mentioned, the easiest way to increase the radar sensitivity is to increase the pulse width. Unfortunately, this deteriorates the range resolution. The easiest way to improve the range resolution is to decrease the pulse width. This, however, decreases the average transmitted power and hence the sensitivity of the radar system.

Pulse compression to the rescue

Pulse compression is a technique that provides both the high sensitivity of wide pulses and the fine range resolution associated with narrow pulses.

Pulse compression is a signal processing technique commonly used in radar, sonar, echography, and optics. It involves transmitting wide pulses that are coded in some way and then processing the received pulses in order to compress them into narrow pulses. The wide pulses provide the average transmitted power necessary to obtain the required sensitivity and hence the required maximum range. The narrow compressed pulses provide the required range resolution.

Pulse compression provides several other advantages:

- The average power of the radar is increased without increasing the peak power or the PRF.
- The coding makes the radar less vulnerable to interfering signals that differ from the coded signal used by the radar.
- Improving the range resolution results in increased clutter rejection. This is especially important when the Doppler shift is insufficient for clutter rejection.

Pulse compression coding gives wide pulses the same large bandwidth as narrow pulses. This increase in bandwidth, combined with pulse compression processing of the received signal, improves the range resolution (decreases $\Delta R$). As a result, a radar using pulse compression can have both long maximum range and fine range resolution.
**Pulse compression coding**

The coding used with pulse compression is a form of modulation. There are two main classes of pulse compression coding:

- Phase-coded (PC) pulse compression
- Frequency modulation (FM) pulse compression, also called “chirp”.

Figure 1-7 shows an uncoded RF pulse and simplified examples of these two classes of coding.

![Uncoded pulse and two types of pulse compression coding](image)

**Uncoded pulse**

**Binary phase-coded pulse**

**Linear frequency modulated pulse**

---

*Phase coding divides a radar pulse into sub-pulses. In this manual, the symbol $T$ is used for the overall width of a coded radar pulse and the symbol $\tau$ represents the duration of a sub-pulse.*

Figure 1-7a shows an uncoded pulse of RF energy. For the duration of the pulse, the frequency and phase are constant. Since the pulse width is $T$, the Rayleigh bandwidth $B = 1/T$. Note that the time-bandwidth product is $T \times B = T/T = 1$.

Figure 1-7b shows a pulse of RF energy that has been modulated using a phase code. The pulse width $T$ has been divided into shorter time segments called **sub-pulses** or **chips** of duration $\tau$. At the beginning of each sub-pulse the phase may change by some amount or it may remain the same. In this example, only two different phases are used in the coding. This is called **binary phase coding** or **biphasic coding**.

With binary phase coding, the **phase increment** (the separation between equally spaced available phases) is $\Delta \phi = 360^\circ/2 = 180^\circ = \pi \text{ rad}$. Phase coding that uses more than two phases is called **polyphase coding**. In this case, the phase increment is less than $180^\circ$.

The bandwidth of the phase-coded signal is equal to the reciprocal of the sub-pulse width: $B = 1/\tau$. The time-bandwidth product is now $T \times B = T/\tau$. Phase coding has increased the time-bandwidth product without decreasing the overall pulse width $T$, that is, without decreasing the energy per pulse. The radar sensitivity for the coded pulse in Figure 1-7b is the same as for the uncoded pulse in Figure 1-7a.
Figure 1-7c shows another type of coding called **frequency modulation pulse compression**, or **chirp pulse compression**. The pulse width is still $T$, but the RF frequency is swept up or down from $f_1$ to $f_2$ during each pulse. The bandwidth of the modulated pulse is $\Delta f = |f_2 - f_1|$. The time-bandwidth product is $T \Delta f$.

Both phase coding and frequency modulation coding increase the **time-bandwidth product** of the coded pulse. This product is a figure of merit for pulse compression systems. The greater the time (pulse width), the better the radar sensitivity. The greater the bandwidth, the better the range resolution. The time-bandwidth product is a measure of both of these parameters together.

Just coding the transmitted waveform does not improve the range resolution. Instead, by increasing the bandwidth, the coding increases the amount of information that the signal carries. This extra information provides a potential improvement in range resolution.

To realize this potential improvement in range resolution, the coded waveform must be compressed at the receiver. Pulse compression processing compresses the received wide pulses into narrow pulses. After compression, the range resolution $\Delta R$ is inversely proportional to the large bandwidth of the coded (uncompressed) waveform.

> The remainder of this manual deals only with phase-coded pulse compression.

### Demodulation

As previously mentioned, a radar receiver demodulates the received pulses of RF or IF energy, shifting the pulse signal down to the baseband. This is usually performed by a quadrature demodulator (also called a quadrature detector or I and Q receiver), as shown in Figure 1-8. This figure also shows an A/D converter and a digital matched filter (correlator) in each channel.

![Quadrature demodulator](image)
The received RF signal may be down shifted to an intermediate frequency (IF) before demodulation. In this manual, the term “RF signal” will be used to refer to the RF or IF signal at the input of the demodulator.

The mixer in each channel of the quadrature demodulator multiplies the received RF signal (Figure 1-9b) by a sinusoidal local oscillator (LO) reference signal (Figure 1-9a) of the same frequency. The mixer output signal (Figure 1-9c) is low-pass filtered or integrated in order to produce a series of baseband pulses in each channel, as shown in Figure 1-9d. (In some cases, the bandwidth limitations of the circuit alone are often sufficient to remove the high frequencies, making a separate low-pass filter unnecessary.)

![Diagram of demodulation process](image)

In Figure 1-9, the phase relation of the RF pulse with the LO signal results in a positive baseband pulse of maximum amplitude. This is not always the case, of course, because the delay between the transmitted and the received pulse, and therefore the phase difference, depends on the target range. In one channel, the baseband pulses can be positive, negative, or close to zero amplitude. Quadrature (I-Q) demodulation compensates for this, however, and the video signal at the output of the magnitude detector is unipolar.

For simplicity, the signals in Figure 1-9 are shown without noise. However, noise is always present in these signals. When the signal returned from a target is weak, with respect to the noise, detection of the target can be very difficult. Since the range of a target is represented by the time delay between the transmitted and received pulses, the receiver must not only detect the presence of pulses in noise, it must precisely determine the delay between each transmitted pulse and the echo of that pulse returned from the target.
Matched filtering

To facilitate target detection, the received signal or the baseband signal can be processed by a device called a matched filter. A matched filter is often used in a radar receiver regardless of whether pulse compression is used or not.

A \textit{matched filter (MF)} is a filter specially designed to provide the maximum signal-to-noise power ratio at its output for a specific, known waveform. It does not preserve the shape of the input waveform, but this is not important since the input waveform is known. What is important in a radar system is to detect the presence of the waveform in a noisy signal and to determine where the waveform lies in time with as much precision and possible.

The matched filter in a radar receiver system accomplishes two things:

- It maximizes the signal-to-noise ratio.
- It produces an output with a sharp peak, making it easier to determine the time at which the signal occurs.

A matched filter can be implemented using digital or analog methods. With digital methods, the baseband signal must first be sampled and A/D converted at regular intervals, as shown by the red marks in Figure 1-9d. This produces a series of numbers (data) that represent the amplitudes of the samples (Figure 1-9e).

A digital matched filter continually compares the sampled input signal with a digital reference signal which is a copy, or replica, of the expected input signal. This is referred to as \textit{active processing}. In a radar system, the input signal is the demodulated and sampled baseband signal, and the reference signal is a digital copy of a baseband transmitted pulse.

The comparison is made point-by-point (sample-by-sample) and with different lag times between the two signals using a mathematical operation called \textit{cross-correlation} (or simply \textit{correlation}). This operation is performed by a \textit{correlator}. Correlation is the best way to detect the presence of a known signal in another signal and to determine precisely where in time the signal to be detected occurs.

A matched filter can also be implemented using analog devices. An analog matched filter is a filter whose frequency response is matched to the frequency spectrum of the input signal. It can be shown mathematically that this type of filter also results in the correlation of the received pulses with a copy of the expected pulse. The use of an analog matched filter is referred to as \textit{passive processing}.

\textit{By definition, a filter is matched if its transfer function is equal to the complex conjugate of the input signal spectrum.}

Autocorrelation can be performed on any signal, including uncoded (rectangular) pulses and phase-coded pulses. Although noise is always present in a radar signal, for clarity, the following figures illustrate the effect of the correlator using signals with no noise.
Figure 1-10 shows an example of a signal consisting of one received, demodulated, and sampled rectangular baseband pulse entering the correlator. The sampling rate is such that 5 samples are taken of each pulse. (Sample values between received pulses are all zero.) The reference date in the correlator corresponds to 5 samples of a transmitted baseband pulse.

For simplicity, the amplitude of both the received pulse and the reference data is equal to 1.

Note that with a rectangular pulse, the output of the correlator (matched filter) has a triangle shape. This is true of both digital and analog matched filters. When a digital correlator containing $N$ reference samples is exactly matched to a rectangular input pulse, the peak amplitude of the output signal is $N$ times greater than the input pulse amplitude. Although radar signals always contain random noise, there is no correlation between the noise values and the reference signal. As a result, the noise amplitude is not increased by the correlator. This results in a significant increase in the peak signal-to-noise ratio.

With a rectangular pulse as input, the waveform at the output of the correlator has a sharp peak. It would be tempting to think such a peak would improve the range resolution. This is not the case, however. Figure 1-11 shows demodulated pulses from two targets. These two targets are separated in range by a distance equal to the range resolution (one-half the pulse length). The two baseband pulses add together to produce one long baseband pulse at the input of the correlator. The correlator output shows that the two targets are not resolved.

In this example, the phases of the two received RF pulses are such that the pulses add constructively. If they add destructively, there will be a null in the composite response and the two targets may be resolved.

![Figure 1-10. Rectangular baseband pulse correlator input and output.](image)

![Figure 1-11. Two consecutive rectangular pulses not resolved.](image)
Phase-coded pulse compression processing

As already mentioned, phase coding increases the bandwidth of a pulse signal without reducing the energy per pulse. Demodulation, sampling, and A/D conversion are performed the same as with uncoded pulses, as shown in Figure 1-12. With phase coding, however, the received signal changes phase during the pulse. This results in a change in polarity of the baseband pulse.

Compression processing is performed in the baseband using a correlator as matched filter. The correlator uses reference data that is identical to that of one baseband transmitted pulse, as shown in Figure 1-13.
Since the signals are bipolar, the samples can be represented using values of 1 and \(-1\). Another common practice is to use the symbols + and – for positive and negative sub-pulses, respectively.

As with the rectangular pulse, when a digital correlator containing \(N\) reference samples is exactly matched to the input pulse, the peak amplitude of the output signal is \(N\) times greater than the input pulse amplitude. Unlike the rectangular pulse, however, the output of the correlator for the coded pulse consists of a very narrow peak (main lobe) as well as low-amplitude sidelobes. It is this narrowing, or compression, of the main lobe that improves the range resolution.

Figure 1-14 shows demodulated phase coded pulses from two targets, targets that are separated in range by less than one-half the pulse length. Without pulse compression, these targets would not be resolved at all. The two pulses add together to produce the correlator input shown in the figure. Although the coded pulses overlap, the output of the correlator consists of two distinct peaks. In this case, pulse compression allows the two closely spaced targets to be resolved.

**Disadvantages of phase-coded pulse compression**

Every technology has advantages and disadvantages and pulse compression is no exception. Pulse compression increases the complexity of the radar system, although this is minor compared to the immense advantages of improved sensitivity and range resolution.

A first disadvantage is that phase coding, by increasing the pulse width, decreases the minimum range at which the radar can detect targets. This is because the radar receiver is blocked during transmission. In radar systems used for air traffic control, this would be a serious drawback as it would prevent detection of nearby aircraft. This drawback can be overcome by transmitting very narrow uncoded pulses for short-range targets between the wide coded pulses for long-range targets.
Another disadvantage of pulse compression techniques is a sensitivity to Doppler frequencies caused by moving targets. The matched filter (correlator) assumes that the received waveform is a scaled and time-delayed replica of the transmitted waveform. If the target is moving toward or away from the radar, a Doppler shift is imparted on the received waveform which causes the phase of the echo waveform to change over time. This represents a potential mis-match in the filtering operation and may result in reduced sensitivity or even prevent detection of the target.

**Range sidelobes**

The greatest disadvantage of pulse compression, however, is the presence of range sidelobes. Range sidelobes are peaks in the correlator output at ranges where no target is present. These sidelobes can be seen in Figure 1-13 and Figure 1-14 as small peaks to either side of the main peak(s). The range sidelobes in the I- and the Q-channels may be both positive and negative. After magnitude detection, however, they are all positive.

Since range corresponds to time in a radar return signal, range sidelobes are sometimes called time sidelobes.

Range sidelobes are an unavoidable consequence of pulse compression. There are, however, many techniques available to minimize their amplitude. One of the most important techniques is to choose a phase code that produces minimal amplitude sidelobes after correlation. A special set of codes called Barker codes provide both good compression and the smallest possible sidelobes when processed using a simple correlator. The longer the Barker code, the greater the compression. A special type of filter called an optimum mismatched filter can further reduce sidelobes.

For even greater compression, other types of phase codes than Barker codes must be used, and much research has gone into developing useful codes. Each different type of code offers certain advantages and disadvantages. In general, the longer the code, the greater the compression. Various types of codes used in radar are studied elsewhere in this manual.

**Summary of advantages and disadvantages**

The advantages of phase-coded pulse compression are:

- The digital methods used provide great stability and reproducibility.
- The selected code is easily changed and can even be modified dynamically.
- It can reduce radio frequency interference (RFI) between adjacent radars.
- It reduces the probability of interception by hostile receivers.
- The transmitted signal has a lower peak power than uncoded pulses offering the same range resolution and maximum range. This allows the use of solid-state transmitters.
The disadvantages of phase-coded pulse compression are:

- It increases the complexity in comparison to radar systems without pulse compression.
- Increasing the pulse width reduces the minimum range.
- It causes sensitivity to Doppler frequencies with moving targets.
- The transmitting and receiving equipment must be designed to accommodate a very large bandwidth.
- The compression process introduces range sidelobes that can be relatively distant from the main lobe.

**Observations on the PPI display**

Figure 1-15 shows a PPI display indicating two targets without pulse compression. The pulse width is such that the target separation is less than one-half the pulse length. As a result, the two targets are unresolved.

![](image)

*Figure 1-15. Two targets unresolved on the PPI display.*
Figure 1-16 shows the same targets and the same overall pulse width, but with pulse compression. In this case, pulse compression allows the targets to be clearly resolved.

Figure 1-17 shows a PPI display of one large cross section target. In this figure, the signal strength is such that some of the range sidelobes exceed the detection threshold and are visible before and after the target.
The Phase-Coded Pulse Compression Processor

Pulse compression is accomplished in this manual using the Phase-Coded Pulse Compression Processor (Figure 1-18).

Each Compressor First Stage in the Pulse Compressor section has a decimation circuit (not shown) at its input. This circuit reduces the effective sample rate of the signal to the selected value (1/ns or 3/ns) before correlation with the selected code. Two D/A converters and filters (also not shown) convert the signals to analog form at the I- and Q-Channel Outputs. All test point signals are in analog form.
The front panel of this module is divided into three sections. The following table describes the elements of each section:

<table>
<thead>
<tr>
<th>Section</th>
<th>Device</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual-Channel Sampler</td>
<td>I- and Q-Channel Samplers</td>
<td>Sample the I- and Q-Channel baseband signals from the receiver and stretch these signals in time to facilitate observation and measurement. The output of each sampler is a discrete signal.</td>
</tr>
<tr>
<td></td>
<td>Origin control</td>
<td>Moves an imaginary “window” towards or away from the radar antenna. This window contains the Range Span, that is, the portion of the total range of the radar that can be viewed and processed at one time. Turning the Origin control clockwise moves the imaginary window away from the antenna. This makes target blips appear to move towards the antenna on the Radar Display and to the left on the Oscilloscope.</td>
</tr>
</tbody>
</table>
| | Span selector | Selects the width of the imaginary window, that is, the extent of the range that can be processed and viewed. Four range spans are available and are indicated by the LEDs:  
  - 1.8 m  
  - 3.6 m  
  - 7.2 m  
  - 12.6 m (all LEDs lit) |
| Pulse Compressor | Compressor First Stage | Decimates the discrete input signal to the selected Sample Rate. Compresses the pulses by correlating the signal with the selected code. With codes requiring two stages of compression, it performs the first stage of compression. |
| | Compressor Second Stage | Used with some compression codes requiring a second stage of compression. |
| | Complementary Code Adder | Used with some compression codes to compute the sum of complementary codes. |
| | Sample Rate | Selects the effective sample rate (after decimation by the Compressor First Stage). |
| | Filters | Selects the filter mode used by the compressors:  
  - Matched: The reference code used by the compressors is identical to the code at the Pulse Generator Output.  
  - Optimum Mismatched: The reference code used by the compressors is an altered version of the code at the Pulse Generator Output. |
| | Test Point Monitors | Allow monitoring the signals at any two test points using an oscilloscope. |
| Pulse Generator | Code Select buttons | Select the code used for pulse compression. The selected code is used to encode the baseband pulse at the Output, which in turn modulates the RF carrier in the transmitter. The selected code is also loaded into the appropriate compressor stages as reference data for correlation with the received pulse signals. |
The Dual-Channel Sampler

The Dual-Channel Sampler consists of two high-speed samplers, one for the I-channel and one for the Q-channel. The operation of these samplers is very similar to that of the Dual-Channel Sampler module used in other manuals of the Radar series.

These samplers stretch the pulse signals from the I and Q channels of the Radar Receiver in time. A repetitive signal can be stretched in time by taking samples of the signal at different points of successive cycles, holding the value of each sample until the next one is taken. This process is similar to that used in sampling oscilloscopes.

The signal at the output of the sampler resembles the signal at the input, except that it has been stretched in time and its bandwidth has been greatly reduced. As a result, the sampler output signal can easily be observed on an oscilloscope. The stretch factor ranges from approximately 41,000 to 289,000, depending on the Range Span selected.

![Diagram of the Dual-Channel Sampler](image)

**Figure 1.19.** Sampler in the Phase-Coded Pulse Compression Processor.

Figure 1.19 shows an input and output coded waveform. The waveforms are shown as ideal (not rounded) in order to clearly show the duration of each sub-pulse in the waveforms. The output waveform is a discrete waveform consisting of 12 samples per sub-pulse duration. The table shows the sub-pulse durations and bandwidths for a typical input waveform and for the corresponding output waveform using different Range Span settings.
Normalization

For all codes, the Phase-Coded Pulse Compression Processor can normalize the output of the compressors by multiplying the output signal amplitude by $1/N$, where $N$ is the code length.

When the LED that indicates the selected code is not flashing, the compressor output is normalized. This ensures that the peak amplitude remains constant regardless of the code selected. With normalization, a longer code results in lower sidelobe levels, rather than a higher peak.

For educational purposes, the Phase-Coded Pulse Compression Processor can produce a non-normalized output for certain codes. These codes are marked with an asterisk on the front panel of the module. When the LED that indicates the selected code is flashing, the correlator results are not normalized. In this case, a longer code results in a higher peak.

**PROCEDURE OUTLINE**

The Procedure is divided into the following sections:

- Setup
- A review of the LVRTS software
- Operation without pulse compression
- Range resolution without pulse compression
- Phase-coded pulse compression
  - Recalibration. Observation of phase codes.
- Range resolution with compression
  - Observations using the Oscilloscope. Observations on the PPI.

**PROCEDURE**

**Setup**

1. Before beginning this exercise, the main elements of the Radar Training System (the antenna, the target table, and the training modules) must be set up as shown in Appendix C.

   Turn on all modules and the target table, and make sure the Power ON LEDs are lit.

   Set the RF Power switch on the Radar Transmitter to the Standby position.

   Make sure the Noise switch under the removable panel at the back of the Phase-Coded Pulse Compression Processor is in the Off (O) position.

2. Turn on the computer, start the LVRTS software, select Phase-Coded Pulse Compression Radar, and click OK.
A review of the LVRTS software

The modules and the LVRTS software of the Radar Processor/Display provide a virtual Oscilloscope and Radar Display (PPI) which are used in this manual. This section provides a brief review of the LVRTS software.

3. In the main window of the LVRTS software, there are four tabs.
   - The Phase-Coded Pulse Compression Radar tab shows how the modules are connected to form an analog radar with phase-coded pulse compression.
   - The MTI Processor tab contains a block diagram of the MTI Processor.
   - The Display Processor tab contains a block diagram of the Display Processor.
   - The RTM Connections tab shows details of the connections to the Reconfigurable Training Module.

   MTI processing is not used in this exercise, although it can be used in conjunction with pulse compression. The test points TP1 and TP2 in the MTI Processor tab are used to connect the oscilloscope probes to inputs 1 and 2.

4. The toolbar at the top of the main window contains tools that allow you to print a diagram, move around in a diagram and zoom in and out in order to see more or less detail. These tools and the corresponding menu commands are described below. Most commands appear in a context-sensitive menu when you right-click on the diagram. They are also available in the File and View menus.

<table>
<thead>
<tr>
<th>Button</th>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Print</td>
<td>Prints the current diagram</td>
</tr>
<tr>
<td></td>
<td>Pan/Select</td>
<td>1-Pans in a diagram. Click and drag with the mouse. In this mode, the mouse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pointer changes when it is over an object you can click on or select.</td>
</tr>
<tr>
<td></td>
<td>Zoom</td>
<td>1-Zooms in or out. Click and then drag the mouse up or down, or click on</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a diagram and roll the mouse wheel.</td>
</tr>
<tr>
<td></td>
<td>Zoom Window</td>
<td>1-Zoom in on a specific region. Click and drag the mouse diagonally over the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>region.</td>
</tr>
<tr>
<td></td>
<td>Home</td>
<td>1-Returns the image to its normal state.</td>
</tr>
<tr>
<td></td>
<td>Previous View</td>
<td>1-Goes back to the previous view.</td>
</tr>
</tbody>
</table>

The menu bar at the top of the window contains all of the menu commands and access to on-line Help. Refer to the on-line Help for detailed information on these commands.
5. At the right of the main window in the LVRTS software is a table of settings entitled System Settings. Similar tables of settings are used elsewhere in the software.

The settings table has two columns, one for the setting names and one for their current values. The column separator can be moved using the mouse, and the entire table can be resized as desired.

Some settings contain numerical values that can be changed simply by selecting or deleting the current value and typing a new value. Other settings have a list of possible values. To change this type of setting, click the setting and then click the down arrow to display a drop-down list from which you can select a new value. You can also double-click the setting name or value to cycle through the available values.

The Restore Default Settings command in the File menu restores the settings in all of the settings tables to their default values.

6. In addition to the tools already mentioned, the toolbar contains buttons for the instruments included in the software. The toolbar buttons and corresponding menu commands, available in the View and Instruments menus, are shown below:

<table>
<thead>
<tr>
<th>Button</th>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Probes Bar" /></td>
<td>Probes Bar</td>
<td>Shows the probes used with the oscilloscope. The probes can be moved using the mouse and attached to any of the test points (TPs) in the MTI Processor and Display Processor diagrams.</td>
</tr>
<tr>
<td><img src="image" alt="Oscilloscope" /></td>
<td>Oscilloscope</td>
<td>Shows the dual-channel Oscilloscope. This is used to observe the signals at the various test points (TPs).</td>
</tr>
<tr>
<td><img src="image" alt="Radar Display" /></td>
<td>Radar Display</td>
<td>Shows the Radar Display, which displays the targets and contains the Radar Display Settings.</td>
</tr>
</tbody>
</table>

Show the Probes Bar and practice connecting and disconnecting probes from various test points as follows:

- To move a probe from the Probes Bar to a test point, click the probe and release the mouse button. Then move the mouse until the tip of the probe is over the test point and click the mouse button to connect the probe.

- To move a probe from one test point to another, move the Pan/Select mouse pointer over the probe until it changes into a grasping hand. Then click the probe and without releasing the mouse button, drag the probe to another test point and then release the mouse button.

- To disconnect a probe, you can right-click the probe and select Disconnect Probe in the context-sensitive menu. Alternatively, you can double-click the probe’s place holder in the Probes Bar.
7. Show the Oscilloscope and examine the different controls. These operate as on a hardware oscilloscope.

   No signals are presently connected to the system.

   The Oscilloscope Settings are presented in a table. These operate as on a conventional oscilloscope.

   The Oscilloscope has a Custom Scale setting for each channel and a Custom Time Base setting.
   - To use a Custom Scale, set Scale to Custom. Two Custom Scale settings are added to the list of settings. Set the first to the desired unit per division the second to the desired value.
   - To use a Custom Time Base, set Time Base to Custom. Two Custom Time Base settings are added to the list of settings. Set the first to the desired unit per division the second to the desired value.

   On the Oscilloscope menu bar, click Help. In the Contents tab, click Oscilloscope. It is suggest that you read the following sections:
   - Overview of the Oscilloscope
   - The Oscilloscope Display

8. Show the Radar Display.

   The Radar Display settings are presented in a table. When you click on a setting, an explanation of the settings appears below the table.

   The Radar Display is for use with the 1.8, 3.6, and 7.2 m Range Spans. The maximum observation range is 7.2 m. The Range setting should always be the same as the Range Span on the Phase-Coded Pulse Compression Processor.

Operation without pulse compression

   The exercises in this manual use the Phase-Coded Pulse Compression Processor. As this module contains a dual-channel sampler, it replaces the Dual-Channel Sampler module used in other manuals of the Radar series.

9. Stop the antenna rotation.

   To stop the antenna from rotating and orient it manually, use any one of the following methods:
   a) Use the Man. (manual) Antenna Rotation Mode and the Speed control on the Antenna Controller. (Select PRF Lock to resume antenna rotation).
   b) Disconnect the cable at the Input of the Antenna Motor Driver and orient the antenna by hand. (Reconnect the cable to resume antenna rotation).
   c) Slightly unscrew the connector at the Power Output of the Antenna Motor Driver and orient the antenna by hand. (Screw the connector back in to resume antenna rotation).
10. Install the small plate target on the mast of the target table.

11. Orient the target table as shown in Figure 1-20. Orient the target so that it is perpendicular to the antenna beam axis, as shown in the figure. 

   With this orientation, the X-axis is the range axis, that is, moving the target along the X-axis changes the target range. This will allow both a fixed target and a moveable target to be placed on the antenna boresight.

Align the antenna with the target.

![Figure 1-20. Position of the target table (X-axis is range axis).](image)

12. Show the Pulse Compression Radar tab of the LVRTS software.

   Select the **Without pulse coding** button and make the connections as shown in the software, *except for the following*:

   - Connect the Test Point Monitor A and B Outputs of the Phase-Coded Pulse Compression Processor to the I- and Q-Channel Inputs of the RTM (that is, to inputs 1 and 2, respectively, of the plug-in module).

     *For details of connections to the Reconfigurable Training Module, refer to the RTM Connections tab of the software.*

     *The Sync. Trigger Input of the Phase-Coded Pulse Compression Processor and the Pulse Generator Trigger Input of the Radar Transmitter should be connected directly to Output B of the Radar Synchronizer without passing through BNC T-connectors.*
13. Make the following adjustments:

On the Radar Transmitter

- RF Oscillator Frequency: Cal.
- Pulse Generator Pulse Width: 1 ns
- RF Power: On

On the Radar Synchronizer / Antenna Controller

- PRF: 288 Hz
- PRF Mode: Single
- Antenna Rotation Mode: PRF Lock

*The Phase-Coded Pulse Compression Processor is designed to operate with a 288 Hz single PRF.*

On the Target Controller

- Mode: Position

On the Phase-Coded Pulse Compression Processor

- Gain (I and Q): slightly above Cal.
- DC Offset (I and Q): mid position
- Range Span: desired observation range
- Sample Rate: 3 ns
- Filters: Matched
- Code: Rect. 1
- Test Point Monitor A Output: TP1
- Test Point Monitor B Output: TP4

14. Calibrate the Radar Training System according to the instructions in Appendix D.

15. In the LVRTS software, make sure the probes are connected as follows:
   - In the MTI Processor tab, connect probes 1 and 2, respectively, to TP1 (I-Channel Input) and TP2 (Q-Channel Input).
   - In the Display Processor tab, connect probe E to TP3 (PRF).
16. Show the Oscilloscope. Then make the following settings.

In the LVRTS software:

Oscilloscope Settings

Channel 1 ...................................................... 500 mV/div
Channel 2 ...................................................... 500 mV/div
Time Base ..................................................... Custom, 0.347 ms/div
Trigger Source ............................................... Ext
Trigger Level .................................................. 2 V

All instrument settings in the exercises are given as suggestions. You can use other settings if you wish.

Continuous Refresh

Set the Oscilloscope to Continuous Refresh (in the View menu, select Continuous Refresh or click the Continuous Refresh button in the Oscilloscope toolbar). You should see two signals on the Oscilloscope screen.

Using the mouse, move the Channel 1 and 2 ground points at the left of the screen so that they are centered in the upper and lower halves of the screen, respectively.

17. On the Target Controller, use the X -axis Position control to adjust the target range so that the peak amplitude of the blip on Channel 1 of the Oscilloscope (the I-channel) is positive and maximized and the amplitude in Channel 2 of the Oscilloscope (the Q-channel) is minimized (close to zero), as shown in Figure 1-21.

To the instructor:

Instead of moving the target in order to maximize the amplitude of the target blip, you can set the RF Oscillator Frequency on the Radar Transmitter to Var and turn the Frequency control very slightly in order to maximize the amplitude on Channel 1. This adjustment is very sensitive.
Range resolution without pulse compression

In this section, you will set up two targets located on the same line of sight but at different ranges. You will use these targets to show that a pulsed radar system without pulse compression has a limited range resolution. You will verify the relationship between pulse width and range resolution.

This is a review of material presented in the manual Principles of Radar Systems.

18. Install the large plexiglass plate target on the fixed mast provided with the target table.

Place the plexiglass target in front of the metal target so that the two targets are 30 cm apart.

Make sure that the plexiglass target is perpendicular to the antenna beam axis, and then tighten the screw in order to secure the target to the mast.

You should see two target blips on the Oscilloscope display: the fixed plexiglass target and the moveable metal plate target. Carefully adjust the plexiglass target range and orientation so that the peak voltage of its blip is positive and at approximately the same amplitude as the metal plate target.

It is not necessary that the amplitudes of both blips in the Q-channel be zero. The I-channel signal is the important one for these observations.

On the Phase-Coded Pulse Compression Processor, adjust the I-channel Gain, if necessary, so that the maximum pulse amplitude is approximately 0.5 V. Change the Q-channel gain by approximately the same amount so that the system remains calibrated.

The display on the Channel-I of the Oscilloscope should resemble that in Figure 1-22.

Figure 1-22. Two targets separated by 30 cm, pulse width = 1 ns.
19. Calculate the theoretical range resolution for each of the pulse widths shown in Table 1-3, using the following equation:

\[
\Delta R = \frac{\Delta T}{2} = \frac{T}{2} = \frac{T \times 3 \times 10^{10} \text{ cm/s}}{2}
\]

<table>
<thead>
<tr>
<th>Pulse width T</th>
<th>Range resolution ΔR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ns</td>
<td></td>
</tr>
<tr>
<td>2 ns</td>
<td></td>
</tr>
<tr>
<td>5 ns</td>
<td></td>
</tr>
</tbody>
</table>

Table 1-3. Theoretical range resolution.

Explain why there are two distinct blips on the Oscilloscope display when the pulse width is 1 ns.

The target separation is 30 cm. Since this is greater than the range resolution for a pulse width of 1 ns, the two targets are resolved.

20. On the Pulse Generator of the Radar Transmitter, set the Pulse Width to 2 ns. The Oscilloscope display may resemble Figure 1-23.

Figure 1-23. Two targets separated by 30 cm, pulse width = 2 ns.
Describe and explain what you observe in the I-channel.

The two targets are just barely resolved or not resolved at all because the range resolution equals the target separation.

\[
\Delta R = \frac{L_p}{2} = \frac{T_c}{2} = \frac{2 \times 10^{-9} \text{ s} \times 3 \times 10^{10} \text{ cm/s}}{2} = 30 \text{ cm}
\]

21. Set the Pulse Width to 5 ns. Describe what you observe on the Oscilloscope display.

The target blips merge together. The pulse width is much too large to resolve targets at this separation.

Two targets separated by 30 cm, pulse width = 5 ns.

What effect has increasing the pulse width on the range resolution of a pulsed radar system?

Increasing the pulse width results in a deterioration of the range resolution (\(\Delta R\) is increased).

22. On the Radar Transmitter, set the Pulse Width to 1 ns.

In the LVRTS software, show the Radar Display and make the following settings:

```
Range ............................................................ same as the Range Span on the Phase-Coded Pulse Compression Processor
```

Always set the Range in the Radar Display Settings and the Range Span on the Phase-Coded Pulse Compression Processor to the same value.
Start the antenna rotation.

If necessary, adjust the Display Threshold on the Radar Display in order to clearly show the two targets.

💡 Since the target amplitude is approximately 0.5 V, try a threshold of approximately 0.3 V.

23. Observe the Radar Display. Then, on the Radar Transmitter, set the Pulse Width to 2 ns and then to 5 ns. Describe what you observe.

With a pulse width of 1 ns, the two targets are clearly resolved. Depending on the Display Threshold, the targets should be barely resolved or not at all resolved with a pulse width of 2 ns. With a pulse width of 5 ns, the targets are not resolved.

Two targets resolved (pulse width = 1 ns).
Targets not resolved (pulse width = 2 ns).

Phase-coded pulse compression

In this section, you will use the Oscilloscope to observe phase-coded baseband pulses before and after compression.

24. Stop the antenna rotation and align the antenna with the targets.

Remove the plexiglass target from the Target Table.

25. On the Radar Transmitter, set the RF Power to Standby. Disconnect the Modulator Pulse Input from the Pulse Generator Output.

26. Show the Pulse Compression Radar tab of the LVRTS software.

Select the With pulse coding button and make the connections as shown in the software, except for the following:

- Connect the Test Point Monitor A and Monitor B Outputs of the Phase-Coded Pulse Compression Processor to the I- and Q-Channel Inputs of the RTM (that is, to inputs 1 and 2, respectively, of the Data Acquisition Interface plug-in module).
27. On the Radar Transmitter, set the RF Power to Standby.

On the Phase-Coded Pulse Compression Processor, make the following adjustments:

- Range Span: desired observation range
- Sample Rate: 3 ns
- Filters: Matched
- Code: Rect. 1

The Rect. 1 code sequence produces a 1 ns pulse with no encoding.

If you don’t see the target blip on the Oscilloscope, turn the Origin Control slightly counter clockwise.

Recalibration

28. On the Test Point Monitors of the Phase-Coded Pulse Compression Processor, select TP1 and TP4. These are the output signals of the Samplers, before the compressor stages.

On the Radar Transmitter, turn on the RF Power.

Recalibrate the system according to the instructions in Appendix D.

You may have to reduce the Display Threshold on the Radar Display in order to see the target on the Radar Display.

Observation of phase codes

29. Stop the antenna rotation and, observing the Oscilloscope, align the antenna with the target. Adjust the target range in order to maximize the I-channel pulse.

30. On the Phase-Coded Pulse Compression Processor, use the Test Point Monitors to observe the signals at TP1 and TP2.

Figure 1-24 shows an example of what you should observe. The Compressor First Stage gives the signal at TP2 a stepped waveform. Other than that, when the Rect. 1 code is selected, it does not otherwise alter the signal.

The input signal to the Compressor First Stage in each channel is a sampled signal with an effective sample rate of 12 samples/ns. The Compressor First Stage decimates this input signal to the selected Sample Rate (1/ns or 3/ns) before correlating the signal with the selected code.

Selecting the Rect. 1 code generates a 1 ns pulse and loads a 1 ns pulse into the Compressor First Stage for correlation with the input signal. Since the sub-pulse width for each code is 1 ns, the autocorrelation of a 1 ns pulse simply results in a 1 ns pulse.
31. On the Phase-Coded Pulse Compression Processor, set the Sample Rate to 1/ns.

Note that the compressor output signal consists of a flat-shaped pulse, but that the output signal appears to be unstable. This is partly because the input pulse may be sampled at any point on its waveform.

In theory, a Sample Rate of 1/ns would be sufficient for pulse compression processing, since the sub-pulse width is 1 ns. This would result in one sample per sub-pulse. Selecting 3/ns results in oversampling, making the steps much smaller in order to facilitate observation and measurement. The system is adjusted so oversampling does not change the amplitude of the compressor output signal (i.e., the amplitude with 3 samples/ns is the amplitude you would expect for 1 sample/ns).

Change the Sample Rate back to 3/ns. At this rate, the overall shape of the pulse is preserved and the signal is stable.

32. On the Phase-Coded Pulse Compression Processor, select Barker 4 normalized (the LED should not be flashing).

Refer to Table 1-4 and adjust the Oscilloscope in order to facilitate observation of the code sequences in the Sampler output signal. (See the explanation below the table.)
Table 1-4. Effective time base on the Oscilloscope (PRF = 288 Hz).

<table>
<thead>
<tr>
<th>Selected Range Span</th>
<th>At 0.145 ms/div</th>
<th>At 0.289 ms/div</th>
<th>At 0.347 ms/div</th>
<th>At 0.361 ms/div</th>
<th>At 0.413 ms/div</th>
<th>At 0.5 ms/div</th>
<th>At 0.578 ms/div</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8 m</td>
<td>0.5 ns/div</td>
<td>1 ns/div</td>
<td>1.25 ns/div</td>
<td>1.43 ns/div</td>
<td>1.7 ns/div</td>
<td>2 ns/div</td>
<td></td>
</tr>
<tr>
<td>3.6 m</td>
<td>1 ns/div</td>
<td>2 ns/div</td>
<td>2.5 ns/div</td>
<td>3.5 ns/div</td>
<td>4 ns/div</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.2 m</td>
<td>2 ns/div</td>
<td>4 ns/div</td>
<td>5 ns/div</td>
<td>6.9 ns/div</td>
<td>8 ns/div</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.6 m</td>
<td>3.5 ns/div</td>
<td>7 ns/div</td>
<td>8.8 ns/div</td>
<td>10 ns/div</td>
<td>14 ns/div</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Spans/10 div: 0.42 0.83 1 1.04 1.19 1.44 1.67

With the Phase-Coded Pulse Compression Processor, each sub-pulse in the radar signal has a duration of 1 ns. The Samplers stretch the baseband signals from the receiver in time, making the pulses much wider.

The effective time base settings in Table 1-4 allow you to view these signals as if they were not stretched in time, using the Custom Time Base on the Oscilloscope. For example, you can set the Custom Time Base so that each division on the graticule corresponds to a whole number of nanoseconds in the unstretched signal (refer to the bold entries in the table).

To display two 1 ns sub-pulses per division, for example, you could:

- set the Range Span to 3.6 m and set the Custom Time base on the Oscilloscope 0.289 ms/div, or
- set the Range Span to 7.2 m, and set the Custom Time Base on the Oscilloscope to 0.145 ms/div.

Both of these adjustments result in an effective time base of 2 ns/div.

You can use Averaging on the Oscilloscope to produce a more stable display.

Figure 1-25 shows the Barker 4 coded pulse (TP1) and the compressed pulse (TP2) displayed on the Oscilloscope using the 3.6 m Range Span. For this figure, the Range Span and the Time Base were set to display two 1 ns sub-pulses per division.
Ex. 1-1 – Introduction to Phase-Coded Pulse Compression ♦ Procedure

The Barker 4 code sequence is shown in Figure 1-25 and below using the symbols “+” and “−”. Considering that each sub-pulse in the unstretched signal has a duration of 1 ns, what is the duration of the entire coded pulse?

Barker 4 code sequence: $+ + − +$

Duration of the coded pulse: $4 \text{ ns}$

How many range sidelobes are present in the compressor output signal? Are all sidelobes of the same polarity?

There are four sidelobes (the peaks at -3, -1, 1, and 3 in the figure below). The sidelobes are not all of the same polarity; two are positive and two are negative.

The following figure shows the theoretical autocorrelation function for the Barker 4 phase code:

![Autocorrelation of a coded pulse](image)

What is the approximate width (duration) of the main lobe of the compressed pulse?

Measure the pulse width at approximately one-half the peak amplitude and give your answer in ns.

In Figure 1-25, the duration of the main lobe is approximately one-half of a division, which corresponds to 1 ns in the Sampler input signal.
33. On the Phase-Coded Pulse Compression Processor, select Barker 5 (normalized) and observe the signals on the Oscilloscope.

![Figure 1-26. Barker 5 code sequence and compressor output.](image)

Enter the Barker 5 code sequence below, using “+” and “−”. What is the duration of the coded pulse?

- Barker 5 code sequence: + + + − +
- Duration of the coded pulse: 5 ns

How many range sidelobes are present in the compressor output signal? Are all sidelobes of the same polarity?

- There are four sidelobes, all of which are positive.

**Range resolution with compression**

*Observations using the Oscilloscope*

34. On the Phase-Coded Pulse Compression Processor, select Rect. 1.

Observe the signals at TP1 and TP4 of the Phase-Coded Pulse Compression Processor. Using the Target Controller, adjust the target range so that the pulse amplitude in the I-channel is positive and maximized and the amplitude in the Q-channel is close to zero.
35. Place the plexiglass target in front of the metal plate target so that the two targets are 30 cm apart, as you did in Step 18. You should see two target blips on the Oscilloscope display, the fixed plexiglass target and the moveable metal plate target. Carefully adjust the plexiglass target range and orientation so that the peak voltage of its blip is positive and at approximately the same amplitude as the metal plate target, as in Figure 1-27. Readjust the range of the moveable target, if necessary, so that it produces no pulse in the Q-channel.

Figure 1-27. Fixed and moveable target blips.

36. Observe the signals at TP1 and TP2 of the Phase-Coded Pulse Compression Processor.

Figure 1-28. Blips from two targets 30 cm apart ($T = 1$ ns).
37. On the Phase-Coded Pulse Compression Processor, select the Rect. 5 (normalized) pulse. The Oscilloscope display may resemble Figure 1-29. Adjust the I-channel DC Offset control to remove any dc offset.

![Figure 1-29. Blips from two targets 30 cm apart ($T = 5$ ns).](image)

Are the targets resolved?

- [ ] Yes
- [x] No

38. On the Phase-Coded Pulse Compression Processor, select Barker 4. If necessary, remove the dc offset. Figure 1-30 shows an example of what you should observe.

![Figure 1-30. Two targets with Barker 4 code.](image)
Are the targets resolved in the compressed signal?

☐ Yes  ☐ No

Yes

Figure 1-31 reproduces a trace similar to the uncompressed pulse signal (channel 1 in Figure 1-30). In the blue boxes in Figure 1-31, write the approximate amplitude (rounded off to the nearest digit) of each sub-pulses using values such as “2”, “1”, “0”, “-1”, and “-2”.

Figure 1-31. Signal in channel 1.
Show that the signal in Figure 1-31 results from two superimposed pulse signals using the Barker code \{1 \ 1 \ -1 \ 1\}.

Since the duration of the combined Barker 4 pulses is equivalent to 6 sub-pulses (6 ns), the lag between the returns from the two targets must be 2 sub-pulses (2 ns).

The following table shows the two uncompressed Barker 4 pulse signals and their sum. The second signal is delayed by 2 sub-pulses.

| 1st signal: 0 0 1 1 -1 1 0 0 0 0 |
| 2nd signal: 0 0 0 0 1 1 -1 1 0 0 |
| Sum signal: 0 0 1 1 0 2 -1 1 0 0 |

The sum signal is shown in the following graph. Note the similarity between this graph and the plot in Figure 1-31.


Are the targets resolved?

☐ Yes  ☐ No

Yes
Note that, in the case of the Barker 5 code sequence generated by the Phase-Coded Pulse Compression Processor, the length of the coded pulse is 5 ns. Compare the resolution obtained using a 1 ns rectangular pulse with no compression, a 5 ns pulse with no compression, and a phase-coded 5 ns pulse with compression.

Without compression, two targets separated by 30 cm are easily resolved using a 1 ns but the targets are not resolved at all using a 5 ns rectangular pulse. With pulse compression, however, the targets are resolved using a phase-coded 5 ns pulse. In fact, the resolution is just as good as with a 1 ns pulse with no compression.

As mentioned in the Discussion, the energy of a radar pulse is proportional to the pulse width. This is true for uncoded and coded pulses. With this in mind, explain the principal advantage of using pulse compression.

Pulse compression offers the advantage of using relatively wide (high energy) pulses while providing the range resolution of narrow pulses. High energy pulses are required for long detection range with adequate signal-to-noise ratio, while narrow pulses are required to distinguish targets that are closely spaced in range.

**Observations on the PPI**

**40.** On the Phase-Coded Pulse Compression Processor, select Rect. 1.

Connect the I- and Q-Channel Outputs of the Phase-Coded Pulse Compression Processor to the I- and Q-Channel Inputs of the RTM (that is, to inputs 1 and 2, respectively, of the plug-in module).

**41.** If necessary, adjust the targets slightly so that both pulses in the I-Channel Output signal have approximately the same amplitude, as shown in Figure 1-33.

On the MTI Processor tab of the LVRTS software, move probe 2 to TP9 and note the peak amplitude of the pulses.

---

**Phase-Coded Pulse Compression Processor settings:**
- Range Span: 3.6 m
- Outputs: I- and Q-Channel

**Software test points:**
- MTI Processor: TP1 and TP9

**Oscilloscope settings:**
- Channel 1 Scale: 200 mV/div
- Channel 2 Scale: 200 mV/div
- Time Base: Custom, 0.289 ms/div (Effective time base: 2 ns/div)
- Trigger Source: Ext
- Trigger Level: 2 V
- Trigger Slope: Rising

**Figure 1-33.** Two targets separated by 30 cm with Rect. 1 code.
Show the Radar Display and set the Display Threshold to approximately one-half to three-quarters the peak amplitude of the pulses at TP9.

42. Start the antenna rotation and observe the Radar Display. It could resemble Figure 1-34. In this figure, the two targets are close to 0° azimuth. The other blips are due to metal objects near the radar.

If necessary, adjust the Display Threshold slightly in order to clearly distinguish the two targets.

Figure 1-34. Targets resolved using narrow pulses without pulse compression \( T = 1 \text{ ns} \).

Are the two targets resolved?

☐ Yes  ☐ No

Yes.
43. On the Phase-Coded Pulse Compression Processor, select the 5 ns rectangular pulse (normalized). Are the targets resolved?

- [ ] Yes
- [ ] No

No. The following figure shows an example of what might be displayed.

![Targets unresolved using wide pulses without pulse compression (T = 5 ns).](image)

44. On the Phase-Coded Pulse Compression Processor, select Barker 4 and then Barker 5, both normalized. Are the targets resolved using these codes?

- [ ] Yes
- [ ] No
Yes, the targets are resolved when Barker 4 and Barker 5 codes are used for pulse compression. This is illustrated in the following figures.

Targets resolved using wide pulses with pulse compression (Barker 4, $T = 4$ ns).

Targets resolved using wide pulses with pulse compression (Barker 5, $T = 5$ ns).
Briefly describe what happens when a Barker encoded pulse is used rather than a rectangular pulse of the same width.

When a wide rectangular pulse is used, two targets spaced closely together in range are not resolved. When a Barker encoded pulse is used, the same energy per pulse is transmitted, but pulse compression allows the targets to be resolved.

45. On the Radar Transmitter, make sure that the RF Power switch is in the Standby position. The RF Power Standby LED should be lit. If no one else will be using the system, turn off all equipment.

CONCLUSION

In this exercise, you reviewed some basic properties of radar signals such as pulse width and bandwidth. You examined the factors that determine the sensitivity and the range resolution of a pulsed radar system and saw how pulse compression is used to improve the performance of the radar system.

REVIEW QUESTIONS

1. What is the advantage of using pulse compression in a pulsed radar system?

Pulse compression provides both the high sensitivity of wide pulses and the fine range resolution associated with narrow pulses.

2. What is the importance of the time-bandwidth product in a pulsed radar system?

The time-bandwidth product is a figure of merit for pulse compression systems. The greater the time (pulse width), the better the radar sensitivity. The greater the bandwidth, the better the range resolution.

3. What two things does a matched filter do to the signals in a radar receiver?

The matched filter maximizes the signal-to-noise ratio. It produces an output with a sharp peak, making it easier to determine the time at which the signal occurs.

4. What is the role of a correlator in a digital phase-coded pulse compression system?

In the receiver system, the correlator compresses the demodulated and sampled baseband pulse signal. It does this by correlating this signal with a digital copy of an encoded baseband pulse.
5. What are range sidelobes and how can they be avoided?

Range sidelobes are peaks in the correlator (or matched filter) output at ranges where no target is present. They are unavoidable, although many techniques exist to minimize them.
Bibliography


